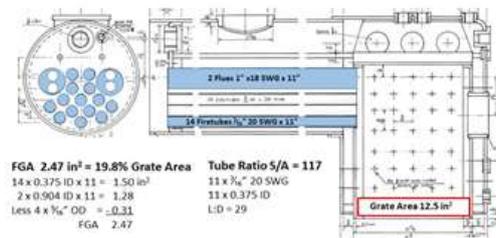




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“Keeping the Kettle on the Boil”

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Most steam locomotive builders follow an existing published model and although they usually build their own boiler it is to the drawings supplied and they are not involved in design decisions. Many of my models are non-standard and to get a suitable boiler I had to look at how things work in the big world as well as in a reduced one. Generally speaking there is little that can be done about the external dimensions of a model boiler, at least if it is to look right, so the barrel diameter is a stock size that can be clothed to give the scale outside diameter, likewise the length of the firebox will be determined by the prototype and its width must fit between the frames, or at least look right for Pacifics.

To avoid getting bogged down with stress calculations I select a published boiler design of suitable diameter and firebox type and adjust its length to suit the model, as long as the cross section and plate thickness are not fiddled with the stresses do not change. One thing that does need some attention is the tube and flue sizes, they are critical to the steaming of the boiler and I have arrived at successful proportions by studying what happens in full size engines as well as in 5"G models. Remember the boiler lies in the middle of the combustion gas circuit after the ashpan / grate and before the smokebox: the whole thing depends on getting the grate & ashpan right and laying out the smokebox draughting to well established principles then the proportions of the boiler tubes are chosen to obtain the correct gas flow through the firebox.

In the 19th century the matter of tube and flue arrangements of locomotive boilers was a bit hit-and-miss and some pretty awful designs were turned out, engines that just would not steam, luckily choosing one of these to model is not necessarily a disaster as long as a bit of internal rearrangement can be carried out. On the other hand some engines were outstandingly successful but I am not sure how much was due to luck rather than know-how. For determining the size of tubes it was eventually discovered that the optimum ratio of the **surface** of the wall of the tubes to the internal cross section **area** needs to be close to 400 (**S/A** ratio), this is equivalent to saying that the length should be 100 times the ID. Deviating on the down side (big short tubes) reduces the heat transfer to the water, going the other way improves transfer but at the expense of greater resistance against the flow of combustion gases thereby limiting the rate of air flow through the grate.

Just to bring a bit of enlightenment to folk not familiar with Wiltshire and its ways, I will mention in passing that GWR standard boilers were notable in scarcely varying from the optimum proportions. The next consideration is the total cross sectional area of the tubes, including unobstructed area of the superheater flues, this is referred to as Free Gas Area (FGA) and quite reasonably it affects the quantity of air drawn through the coals, for normal combustion rates an area equivalent to 15% of the grate area was found to be fine. These "norms" for S/A and FGA are not fundamental scientific relationships but rather the result of actual experience and tests, however they turn out to be quite critical requirements for a satisfactory Stephenson railway locomotive.

For 5"G miniature locomotives the ideal Free Gas Area ratio works out to be the same at 15% but the S/A ratio is very different: why is this? At first glance the similarity of the FGA ratio appears to be reasonable as it seems likely that if 1 sq.ft of firebed on an LMS 5P5F needs about 0.15 sq.ft of tube area for gas flow then 1 sq.in on the model will need 0.15 sq.in. A bit more thought introduces doubt since it seems strange that coals 1" deep on a model need as much air as a 12" bed of fire does on a big 'un. Part of the explanation could well be the added resistance of a firebed composed of very small coal as well as the relative efficiencies and rates of working: a Class 5 working fairly hard gets through something like 80 lb of coal per sq.ft of grate area each hour while a typical IMLEC contender running at between 1 and 2 % efficiency burns coal at a rate of something like 30 lb/ft²-hr, not 7 lb/ft²-hr as we might expect, so combustion rate does not reduce proportionally. It looks as though the 15% FGA figure for the model is just coincidental. On the other hand the S/A ratio of the tubes turns out to be quite different for models: a typical 13ft firetube of 1 $\frac{9}{16}$ " ID with S/A 400 would become a model tube of 14" x 0.14"ID that will definitely not pass much air.

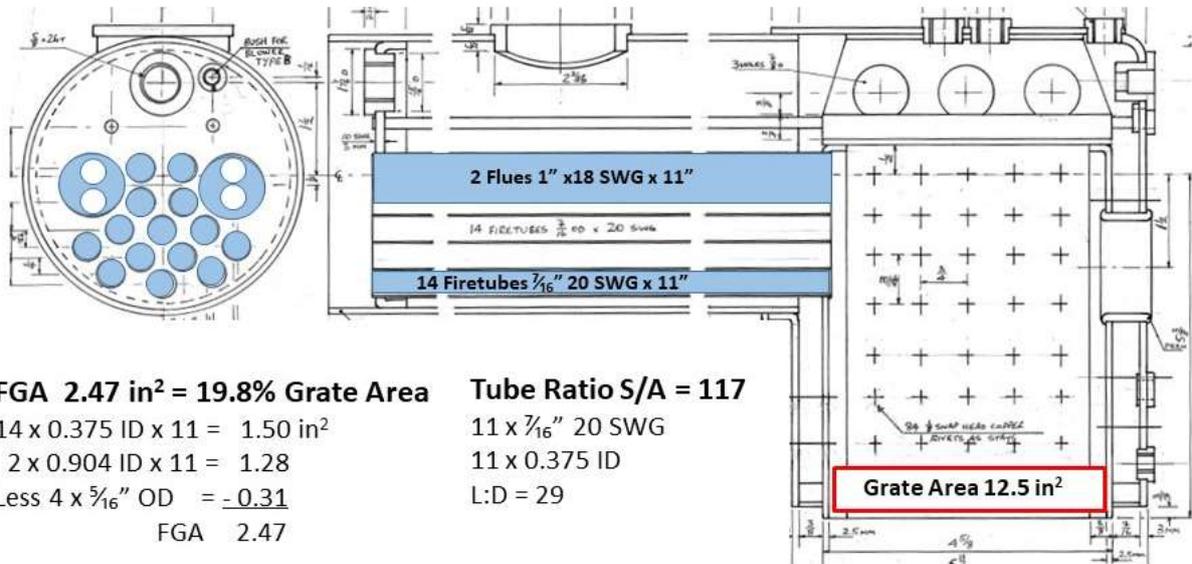
The reasoning is a bit complicated but roughly speaking although the same number of scaled down tubes provides the correct scale Free Gas Area, the resistance to gas flow per square inch of cross section is considerably bigger. This is due to the increase in the ratio of wall area to cross section (reduced hydraulic depth) despite the shorter length. The net result is the need to increase the tube size in the model to 3 or 4 times what its "true scale" diameter would be so that the scaled down volume of gas can be passed by each square inch of area. Typically tubes of 14" length are made from $\frac{1}{2}$ "OD 20G tube, about $\frac{7}{16}$ "ID giving S/A = 130 (or L/D = 33). I have found this to be fine, Length \approx 33 times ID. A shorter boiler of say 11" between tube plates will need an ID around 0.33", say $\frac{7}{16}$ " 20G. While this definitely works for our engines, we shouldn't fool ourselves into thinking it is good, for in order to "fix" the problem of draughting (how to draw sufficient air through each square inch of fire bed) the tube proportion has been changed so that there is less than a third of the heating surface that the full-size S/A of 400 would provide. The reduction of heat transfer in the tubes makes our engines more reliant on the firebox heating surface to generate steam with only a little help from the tubes, a good reason for $\frac{5}{16}$ " or more water leg spaces to improve circulation round the firebox. The world of model engineering is no different from the big world, we do what all engineers do, trade off one effect against another: in this case it is far more important to pass sufficient air to generate a hot burning fire than to try and extract the last "ounce" of heat in the tubes, we aim to get the heat from the firebox area and put in radiant superheating.

So let's see how things work out for a 5"G model: the outside dimensions and grate area will be determined by the model itself, this in turn will fix the distance between tube plates and hence tube length. Choose a tube size so that the ID is about 1/33 length, see how many tubes can be fitted and calculate the FGA (total internal cross sectional area including unobstructed area of superheater flues), if it turns out to be around 15% of grate area, or more, all is well. When the model is based on a well-designed prototype things are usually fine but if the FGA is deficient then the juggling starts. By increasing the tube diameter one size the number of tubes that fit will decrease but the total area will improve, this is the route to getting a reasonable FGA ratio: the heating surface reduces but adequate gas flow through the grate is achieved. A boiler of these proportions with the correct smokebox draughting will be a delight to fire. Finally, if it proves

impossible to get a good arrangement within the overall shape of the boiler perhaps it would be better to forsake the chosen prototype and select one designed by a smarter CME, or better said, CME with a good Drawing Office.

The drawing of the boiler for my 5" G Whitworth shows it does not have ideal proportions, I decided to follow the ratios of the prototype with firetubes big for their length (low S/A ratio) and Free Gas Area well over 15% of grate. The model "suffers" from the same symptoms as the big Jumbos: incredibly hot fire, bags of steam to flog the engine, a joy to run but the driver loses his coal bonus.

5" GAUGE LNWR BOILER



FGA 2.47 in² = 19.8% Grate Area

14 x 0.375 ID x 11 = 1.50 in²

2 x 0.904 ID x 11 = 1.28

Less 4 x 5/16" OD = -0.31

FGA 2.47

Tube Ratio S/A = 117

11 x 7/16" 20 SWG

11 x 0.375 ID

L:D = 29

Grate Area 12.5 in²